The Binary Logic Justification Report

Purpose of This Report

A recent review of the Microfluidic Blood Typing Cassette (the mechanical/reagent-delivery subsystem) raised a concern that the design under discussion did not clearly reflect the patent's core principle: that a single analog blood sample input must yield only one possible digital binary logic output.

That review concerned the mechanical cassette work being developed separately. This note describes the electronic subsystem being developed in parallel, and clarifies how it is specifically designed to implement the patent's binary logic requirement, independent of the mechanical delivery method used on the reagent side.

Core Patent Principle Being Implemented

The patent's central requirement is that the device must convert a single, one-time biological reaction (an analog, physical event: agglutination or no agglutination in a reagent zone) into exactly one binary digital value, and that these binary values must be resolved through a fixed logical mapping structure into exactly one final blood type classification never a range, an analog signal, or an ambiguous output.

Electronic Subsystem implementation logic

The electronic reader subsystem being developed performs the binary conversion and logic resolution stage of the patent, as follows:

- Each reaction zone (Anti-A, Anti-B, Anti-D, and Control) has exactly one dedicated optical sensor. Each sensor takes exactly one analog physical input per test: the reflectance state of its zone at the end of the reaction period.
- The firmware reduces that single analog reading to exactly one binary digital value per zone (1 = reaction/agglutination present, 0 = absent), using a fixed threshold. No intermediate or partial value is ever exposed or stored.
- The three antigen-zone binary values are passed through one fixed logic table (equivalent to the patent's disclosed truth table), which produces exactly one final digital classification one of the eight standard ABO/Rh blood types.
- The control-zone binary value is used only to validate the test as a whole; it does not alter the blood-type output; it only confirms whether that single output should be accepted as valid.

In other words: one blood sample in, one binary decision per antigen zone, one fixed logic resolution, one digital blood-type output. There is no analog or visual interpretation step in this subsystem the sensor-to-classification path is entirely digital and singular per test, which is the specific behavior the patent requires.

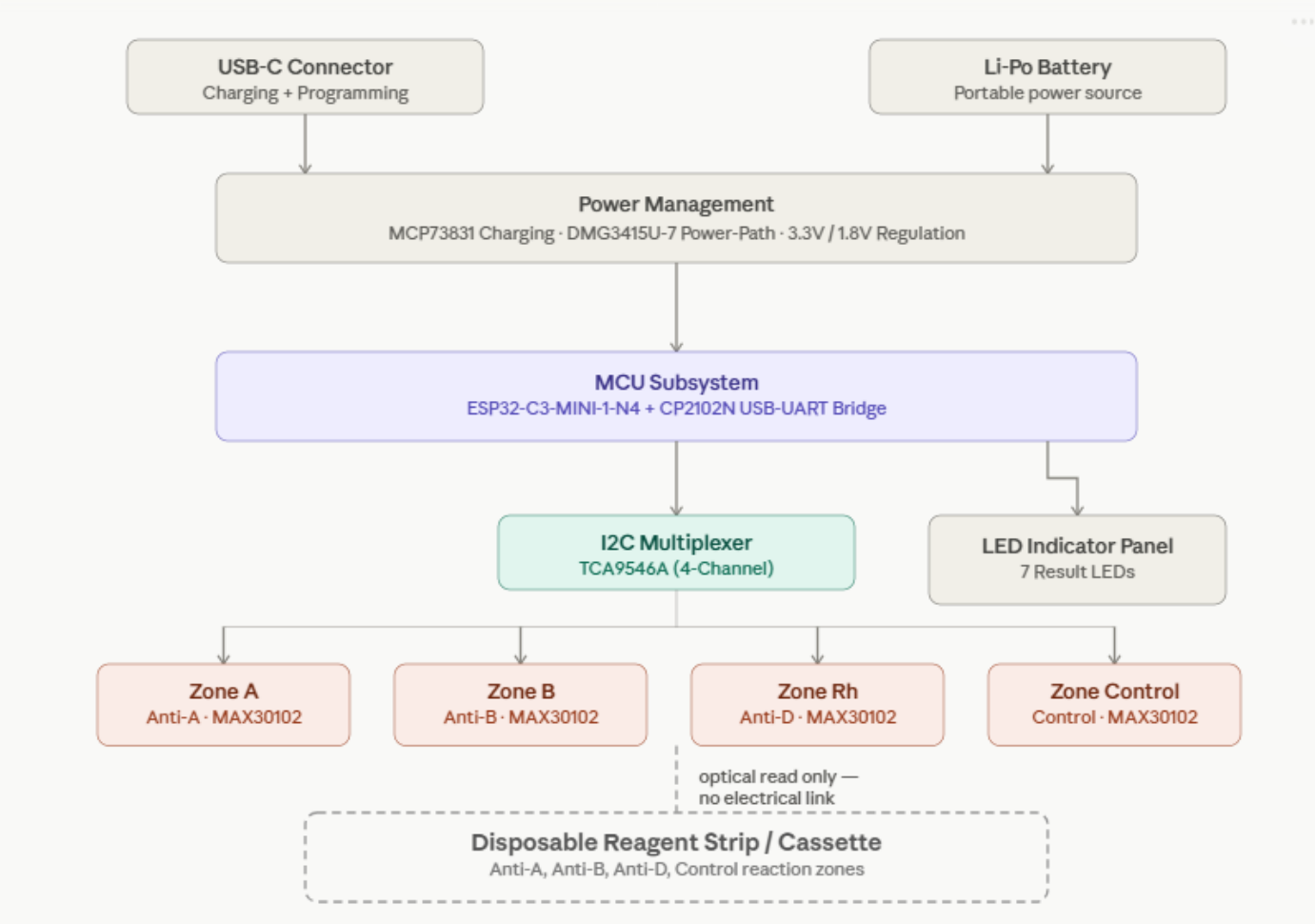
System Architecture

At a high level, the device consists of a power supply chain, a central microcontroller, a multiplexed array of optical sensors, a bank of result-indicator LEDs, and a USB interface used for programming, debugging, and charging.

The signal flow through the system is as follows:

- The disposable strip is inserted so that its three reagent zones (anti-A, anti-B, anti-D) and one control zone align with four onboard optical sensors.
- Each optical sensor measures the reflectance/agglutination state of its corresponding zone and communicates the result to the microcontroller over an I2C bus, routed through a 4-channel I2C multiplexer.
- The microcontroller thresholds each sensor reading into a binary value (1 = agglutination / antigen present, 0 = no agglutination / antigen absent).
- The three binary values (plus the control-zone validity bit) are passed through firmware logic equivalent to the patent's described truth table, yielding a definitive ABO and Rh blood type classification.
- The result is displayed via dedicated indicator LEDs (A, B, AB, O, Rh+, Rh-, and a Control/valid-test indicator).

System Block Diagram



Components Used

The table below lists the primary active components used in the current design, organized by functional role.

Component	Part Number	Function
Microcontroller	ESP32-C3-MINI-1-N4	Main processing unit; runs the binary logic classification firmware and controls all peripherals. Includes integrated Bluetooth Low Energy for optional wireless data output.
USB-UART Bridge	CP2102N-A02-GQFN28	Provides a USB interface for firmware programming, debugging, and serial communication with a host computer.
I2C Multiplexer	TCA9546APWR	4-channel I2C switch that isolates each optical sensor onto its own bus channel and performs voltage translation between the 3.3V main bus and the 1.8V sensor-side bus.
Optical Sensors (x4)	MAX30102EFD+T	Integrated LED + photodetector reflectance sensors used to optically detect agglutination in the anti-A, anti-B, anti-D, and control reagent zones.

Working Principle

Sample Application and Antigen-Antibody Reaction

A small whole-blood sample is applied to the disposable strip's sample application area. Capillary action or microfluidic channels distribute the sample to the anti-A, anti-B, anti-D, and control reagent zones. Where an antigen corresponding to a given reagent is present on the red blood cells, an agglutination (clumping) reaction occurs in that zone; where the corresponding antigen is absent, the zone remains a smooth, unclamped suspension.

Optical Agglutination Detection

Each of the four MAX30102 sensors is positioned directly beneath one reaction zone on the strip. The sensor's integrated LED illuminates the zone, and its photodetector measures the reflected light intensity. An agglutinated (clumped) zone scatters and reflects light differently from a smooth, non-agglutinated zone, producing a measurably different sensor reading.

The MAX30102 was selected for this role due to its small, wearable-grade package, integrated ambient-light rejection, and digital I2C output, which simplifies signal acquisition compared to a raw analog photo-reflective sensor.

I2C Data Acquisition and Multiplexing

Because all four MAX30102 sensors share the same fixed I2C address, each sensor is connected to its own channel of the TCA9546A I2C multiplexer. The microcontroller selects one channel at a time and reads that sensor's optical data, cycling through all four zones (anti-A, anti-B, anti-D, and control) each test cycle.

The multiplexer's channel-side I2C lines are pulled up to the sensor's 1.8V supply, while the main-side lines are pulled up to the system's 3.3V logic rail; the TCA9546A performs the necessary voltage translation between these two domains.

Binary Logic Processing (Firmware)

For each of the three antigen zones, the firmware compares the sensor's reflectance reading against a calibrated threshold and assigns a binary value: 1 if agglutination (antigen present) is detected, 0 if not. This directly implements the patent's described approach of converting biological agglutination reactions into binary output values.

The three binary values are then evaluated against a fixed lookup table functionally equivalent to the patent's disclosed truth table / logical mapping structure — to determine the corresponding ABO and Rhad blood type:

Anti-A	Anti-B	Anti-D (Rh)	Result
0	0	0	O negative
0	0	1	O positive
1	0	0	A negative
1	0	1	A positive
0	1	0	B negative
0	1	1	B positive
1	1	0	AB negative
1	1	1	AB positive

The control zone reading is used independently to validate that the sample was properly applied and that the reagents reacted correctly; if the control zone does not read as expected, the result is flagged as invalid rather than being reported as a blood type.

Result Indication

Once classified, the result is displayed to the user through seven dedicated indicator LEDs, directly driven by microcontroller GPIO pins: A, B, AB, O, Rh+, Rh-, and a Control/valid-test indicator. Each LED is switched on according to the firmware's classification output, giving the user an unambiguous, easy-to-read result without requiring interpretation of colour changes or agglutination patterns by eye.

Summary

The electronic work currently in progress is the binary logic processing layer of the patent: it takes exactly one analog reaction state per reagent zone and produces exactly one digital binary output per zone, resolved into exactly one final blood type classification through a fixed logic table. This satisfies the patent's core "single analog input, single digital binary output" requirement independently of the mechanical reagent-delivery method.